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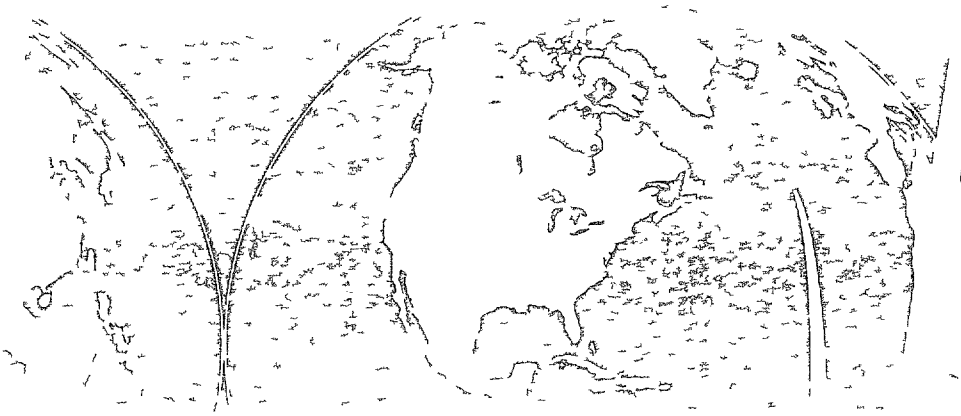
Renewable Energy for Agriculture



To the Reader

Over the last decade the introduction of reasonably priced and reliable renewable energy systems has made it possible for agricultural enterprises in the developing world to tap local renewable sources of fuel — sunlight wind biomass hydro and geothermal — to supply electrical and thermal loads A number of international national and local public and private sector organizations are now working with agricultural enterprises in the developing world to effectively integrate renewable energy systems USAID s Office of Energy Environment and Technology has commissioned this guidebook to highlight a few of the Agency s programs and to help communicate the considerations and some comparisons in the selection of alternative renewable energy systems for agricultural applications

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Introduction

It is impossible to envisage an effective food cultivation and production system, or an efficient food processing and distribution system, without the energy inputs that make these systems operate There is a close correlation between the quality and quantity of the food an agricultural enterprise produces and the quality and quantity of the energy used to "turn the wheels" of the agricultural process

Throughout the developing world, rural areas' lack of reliable, efficient energy limits the ability of agricultural enterprises to develop economically Adequate energy supplies do not reach these rural enterprises for many reasons, including the high cost of providing fuel and maintenance networks to supply conventional diesel generation equipment, the often prohibitive cost of grid extension to remote regions with dispersed populations, and the lack of access to, financing for, and training in renewable energy generation technology As a result, agricultural practices in the developing world remain largely based on human and animal power, two traditional sources of power with major drawbacks Human muscle requires extensive food and care relative to output The productivity of animal muscles is also relatively low compared to food and care requirements, and using animals as a source of labor can ultimately lower milk and meat production

To eliminate human drudgery and increase agricultural productivity, there is a strong need for sustainable, efficient energy inputs Agricultural operations can benefit from renewable energy technologies in several fundamental areas (1) opening access to new or enhanced techniques that improve agricultural yields (land preparation, planting, irrigation, fertilizing, and harvesting) and quality of life on the farms (lighting, health, and education), (2) opening access to post harvest enterprise opportunities (transport, processing, storage, and preservation), which add value to the farm products and provide income to the operators, and (3) adding value to agricultural waste

Renewable energy systems — based on energy sources such as biomass, water, wind, geothermal, and the sun — can provide clean, sustainable energy for many critical agricultural needs The systems can be easily sized to meet the exact energy needs of an agricultural operation and designed to offer easy maintenance, use local fuels — which do not require scarce foreign exchange to purchase — and are usually environmentally benign On a lifecycle cost basis, renewable systems have proven to be the least cost alternative in thousands of agricultural applications worldwide under a broad range of diverse operating conditions

The U S Agency for International Development s (USAID) Office of Energy, Environment, and Technology (EET) spearheads the U S government's efforts to help developing countries design and execute programs that are directed at overcoming market and institutional barriers to the expanded use of renewable energy systems USAID activities in renewables can be divided into six categories

1 Supporting the adoption and implementation of policy or regulatory changes that clarify or establish rights and incentives for renewables

2 Training entrepreneurs, operators, technicians, policy makers, and financiers in all aspects of the development of renewable energy projects and programs

3 Fostering the start up of new renewable energy businesses and mobilizing existing business entities to pursue renewable energy

4 Leveraging increased financial commitment to renewables from the public and private sector

5 Stimulating the establishment or strengthening of host country nonprofit institutions for the explicit purpose of promoting renewables

6 Disseminating the lessons learned (or technical information) on how renewables have been used effectively

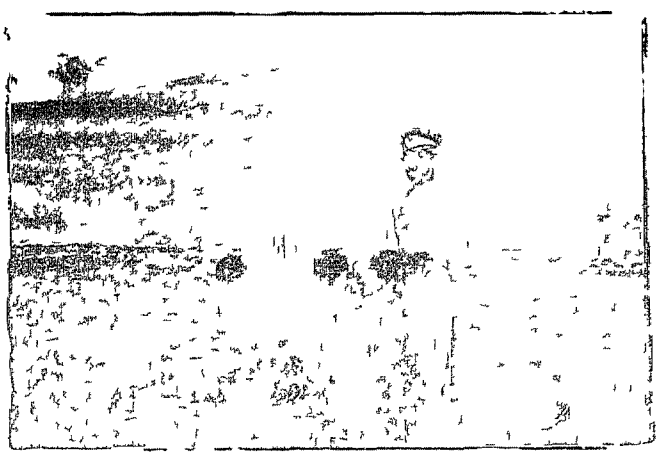
USAID executes programs in each of the six categories designed to promote the use of renewables in agricultural applications where they are economically and technically competitive

This guide provides a general introduction to the role renewable energy can play in the development of agricultural operations While the guide is not meant to be a design manual, it can provide a useful introduction to renewable energy systems The links that are included at the back of this guide point the reader to organizations that offer additional information on determining the most appropriate renewable energy system to meet specific requirements of an agricultural enterprise

Applications

Irrigation is the second most energy intensive activity in agriculture, following fertilization. Irrigated land must increase substantially if food production in the developing world is to be dramatically increased. The low economic feasibility of irrigation in significant areas of the developing world is the greatest obstacle to agricultural expansion due to higher initial investment costs, low crop intensities, market limitations on crops, and the lack of an irrigation tradition.

The advent of cheap, dependable, renewable energy powered motor and pump sets has revolutionized irrigation. In many parts of the world, gravity flow techniques cannot irrigate large tracts of land economically. Small, renewable energy powered pump sets have begun to play a critical role in augmenting the land available for food production. In the photo below a farmer and his children on the Island of Sumba, Indonesia, frolic in the spray of the farm's irrigation system. The water for the impact sprinklers is pumped from a well by a Bergey Wind Power 10 kilowatts (kW) water pumping system. The sprinklers supply water to two fields and the farm's livestock. Water from the pumping system is also used by the farmer and his family to wash clothes and take showers. The project was designed with technical assistance from Winrock International — supported by USAID's Office of Energy, Environment, and Technology — and funding from USAID/Jakarta.



Water Supply

Safe, reliable, and convenient water supplies — whether for drinking, processing, irrigation, or livestock — are critical for the development of agricultural enterprises. In spite of technological achievements, many small scale agricultural enterprises in rural areas of the developing world rely on manual labor to collect, pump, and/or distribute water. Surface water collected from such sources as lakes and streams is prone to contamination. In addition, the vessels used to draw and transport water from surface sources or from hand dug wells may induce contamination.

In areas where the water table is deep, well volumes high, and resources widely dispersed, the physical burden on the animals and/or humans powering the water pumping and distribution systems can be overwhelming and inefficient. This excess load can ultimately lower their ability to perform other tasks.

Photovoltaic (PV) and wind powered water pumping and distribution systems are likely to be more competitive compared to human or animal powered water lifting or distribution methods. These technologies are also the economically rational choice when compared to conventional diesel generators in areas where fuel supplies and maintenance are expensive. As a result of these benefits, hundreds of PV and wind powered pumping and distribution systems have been installed worldwide, supplying water for human consumption, livestock, and small scale irrigation.

The size of the renewable energy power system required for water delivery depends on the daily volume of water required, the renewable resource availability (hours and intensity of sunlight, average wind speed, etc.), the system efficiency, and the total pumping head. The daily water consumption depends on the intended use. Sizing of a renewable energy based electric pumping system should be based on monthly or yearly data representing the renewable fuel source availability and the total water requirement. Examination of monthly or yearly data can be used to identify those months during which the water demand is highest and thus determine the maximum size of the system necessary to meet the demand. Water pumping systems should also be sized to accommodate expected demand growth to the extent that it is economically feasible.

Mid- and Large-Scale Drying and Processing

Agricultural processing is a key economic activity in most developing countries Processed agricultural commodities are a major source of foreign exchange, employment, and industrial development

Mid and large scale agricultural processing industries are a major consumer of fossil fuels As energy costs begin to dominate production costs, these industries are turning to previously unused or underused agricultural residues to meet their thermal and electrical energy needs

The initial cost of agro residue fired plants is usually slightly higher than conventional plants On a lifecycle basis, however, they generally produce thermal and/or electrical energy at a lower cost than fossil fuel fired boilers even if the biomass fuel stock has to be dried or pretreated before being used as a fuel

A number of energy conversion devices are commercially available that use agricultural residues — such as bagasse (sugar cane residue) ground nut shells, cotton lint, coconut husks, rice hulls, and palm oil — as feed stocks Available conversion technologies include direct combustion, anaerobic digestion, and biomass gasification Still, a great variety of agricultural residues (e g , olive pits, coffee waste, cacao caboose, and oil palm ears) remain under utilized and the efficiency of current energy production methods can be greatly increased

High efficiency, biomass residue based electric generation systems can be linked to a grid The sale of excess electricity can help an enterprise increase its revenue stream, expand off season employment, dispose of accumulated residues, and increase the supply and reliability of local power

Agricultural processing industries with high hot water requirements, not located near sources of cheap, combustible agricultural residues — such as dyeworks, spinning and weaving factories, and food processing plants — typically use electricity, liquefied propane gas (LPG), and/or fuel oil to meet their thermal requirements All of these are costly and often require imported fuel, which can further increases their price Proven, cost effective renewable energy systems can be used to meet the thermal needs of agricultural processing industries

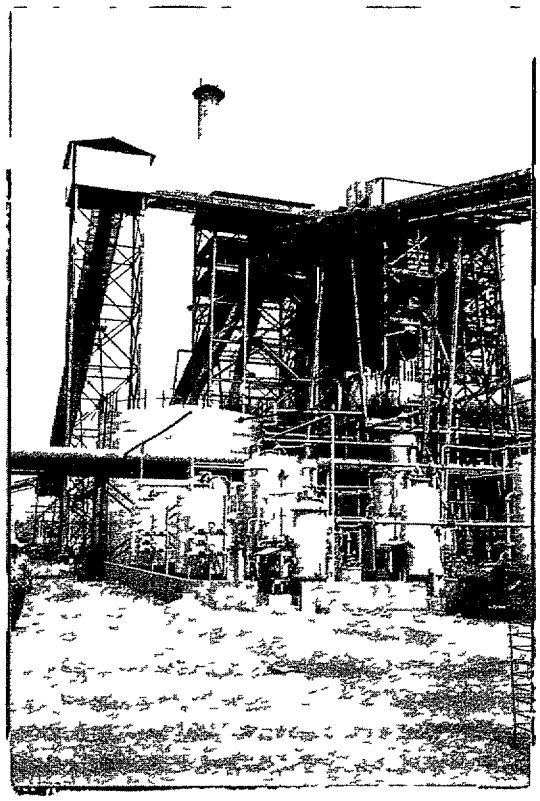


Photo courtesy of Winrock International

USAID is implementing a $19 million Greenhouse Gas Conversion Pollution Prevention Initiative in India in collaboration with several Indian and U S public and private sector partners, including Winrock International A principal component of this initiative is the Advanced Bagasse Cogeneration (ABC) Program Until recently most sugar mill bagasse combustion systems in India were designed to meet the electricity and thermal needs of the mill The ABC Program is helping Indian sugar mills like the Tamil Nadu facility in the photo above design bagasse based cogeneration systems that maximize combustion and electrical output, operate throughout the year, and have the potential to supply electricity to the grid

USAID's Office of Energy, Environment and Technology also sponsored Winrock International to execute a series of policy studies and technical assistance projects designed to open the markets for bagasse cogeneration in India These activities led to breakthroughs in power purchase pricing in all of India's key sugar producing states, providing direct incentives to investments in cane cogeneration Almost 300 MW of installed capacity can be tied to USAID's work in promoting bagasse cogeneration in India

Winrock International's Renewable Energy Project Support Offices (REPSOs) are part of the organization's strategy to help local people find appropriate and environmentally sustainable solutions to their energy and income needs. The REPSOs — managed as local organizations in coordination with Winrock and partially funded by USAID's Office of Energy, Environment and Technology — foster cooperation among government agencies, private enterprises, nonprofit organizations, and communities in common pursuit of harnessing proven technologies for sustainable energy development.

In the photo above, Benjamin Quic picks shade grown coffee on a cooperative in Guatemala. Quic's cooperative joined forces with Winrock's REPSO in Guatemala (Fundacion Solar) and Guatemala's National Association of Coffee Producers to execute a project that studies linkages between trading carbon permits and the sustainability aspects of small scale coffee production chains in Central America. Fundacion Solar is also involved in several projects related to biomass use in coffee processing as well as in assisting small coffee processors in Guatemala to improve energy consumption in processing facilities and to develop systems that will make biomass supply more sustainable in years to come.

Small-Scale Drying and Processing

Crop drying and processing is particularly important for small scale agricultural operations, as it can substantially increase potential profits — processed crops usually fetch a higher market price.

Workers on small scale operations often face the enormously time consuming and back breaking chores of manual milling and hulling. The hand milled kernels often break, lowering their sale value. Animal powered grinding is often an inefficient alternative, as it requires large inputs of food and fodder per unit produced. Sole reliance on human and animal muscle not only places a burden on the laborer, but also restricts the small scale agricultural enterprise from exploring other more energy intensive food processing options, such as oil expelling, roasting, and packaging.

Traditional methods of open air drying invite contamination and losses from birds, insects, and rodents and can result in uneven drying, which can drastically reduce the sale value of the product.

Renewable energy technologies offer efficient and cost effective techniques for small scale drying and processing of agricultural commodities. For example, simple solar and biomass fired crop dryers can significantly reduce crop losses from uneven drying and/or animal scavenging.

Additional Applications

Water Treatment – Readily accessible clean water for drinking and hygiene is a common and serious health concern on agricultural operations in the developing world.

A number of low cost, nonelectrical means of treating water are available to make it safe for human consumption. Pasteurization and distillation are two common effective methods for treating biologically contaminated water. Water or milk may be pasteurized by heating it to 65° C (150° F) for 30 minutes or 71° C (161° F) for 15 seconds. Pasteurization disinfects microbiologically contaminated water and milk by killing viruses, bacteria, and protozoans. Distillation will remove bacterial, viral, and chemical contaminants from brackish or salt water, making it drinkable.

Renewable energy sources can be tapped to treat water For example, pasteurization may be achieved by placing water or milk containers in solar cookers Solar thermal energy is used to heat the water in the cooker by means of insulation and reflectors under a transparent surface Solar stills distill water by heating it to form steam and then allowing it to condense back to water These solar energy-based systems are good alternatives to using wood stoves to boil water, as they do not require scarce biomass fuel resources to supply heat

More sophisticated means of water treatment generate higher volumes of potable water and are effective in eliminating a wider variety of contaminants Two modern forms of water treatment, ozone treatment and photochemical (UV) disinfection, both have very low electrical power requirements and are therefore easily powered by small scale renewable energy systems, such as PV or small wind turbines

Lighting – Electric lighting offers a quality of light with which traditional sources, such as gas and kerosene, cannot compete Kerosene lights are also known safety hazards and contribute to unhealthy indoor air quality Electric lighting can extend an enterprise s hours of operation, increase community safety, and help improve other personal residential and professional conditions

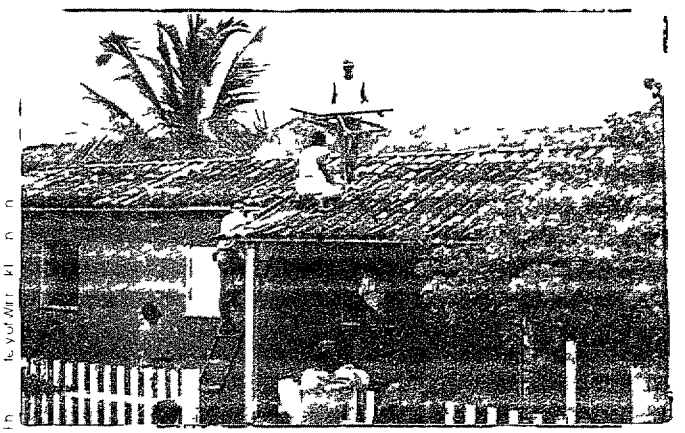
When using a renewable energy system for lighting, energy efficiency is the key to reliability and affordability A dollar spent on efficiency will generally save many dollars in total systems costs Compact fluorescents are the lights of choice for renewable energy systems, giving four times as much power per watt consumed as incandescent bulbs With an expected service life of 10,000 hours, they can last 10 times longer than incandescent bulbs

Communications – Radio, radiotelephone, and televisions provide market news/data services that can help strengthen agricultural enterprises, including helping augment the formal and informal education of the staff that manage and work them Radio and television systems broadcast educational programs and introduce agricultural workers to events and changes happening outside their local area

Data monitoring is a specialized communications application that requires trained technicians The information it provides, however, can often yield significant benefits for agricultural enterprises For example, monitoring instruments provide data on precipitation levels and intensity, river levels, humidity, soil moisture, leaf wetness, and many other factors This data can help farmers properly plan for planting, harvesting, and irrigating crops as well as timely pest management applications

Basic communications systems require very little electric energy Stand by power consumption may be as little as 2 watts (W) Power consumption for transmitting and receiving are usually higher, on the order of 30-100 W, but generally are for a very short time span A single 30 W PV module can provide sufficient power for reliable communications via VHF radio or a television, while larger renewable energy based generation units can power microwave repeater stations and satellite ground systems

Electric Fences – PV is now the technology of choice to power electric fences, as it eliminates the frequent replacement of expensive batteries, increases system reliability, and is a portable power source



The installation of a photovoltaic module will provide the electricity needed to power a lighting system in this home in Guatemala

> *Electric lighting offers a quality of light with which traditional sources, such as kerosene and gas, cannot compete*

Technology Summary

This section gives a brief overview of several of the renewable energy technologies typically used in agricultural applications

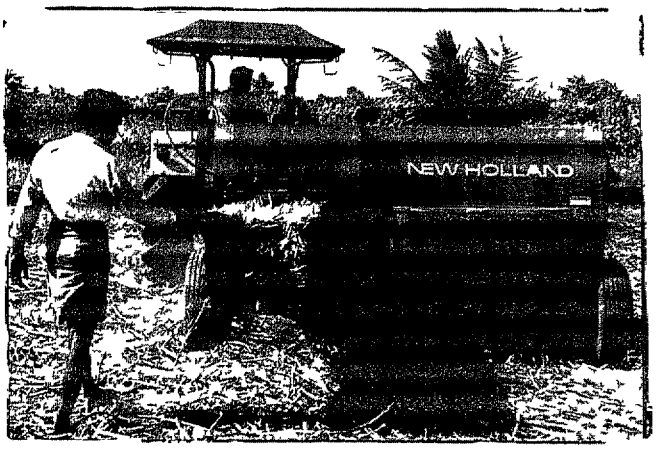


Photo [illegible]

Workers bale cane trash for the Mohan Breweries and Distilleries Limited bagasse cogeneration facility in Tamil Nadu India

High-quality biomass combustion systems currently generate hot water, steam, and electricity for industries, including forest products and food processing, electric utilities, and specialized markets

Biomass

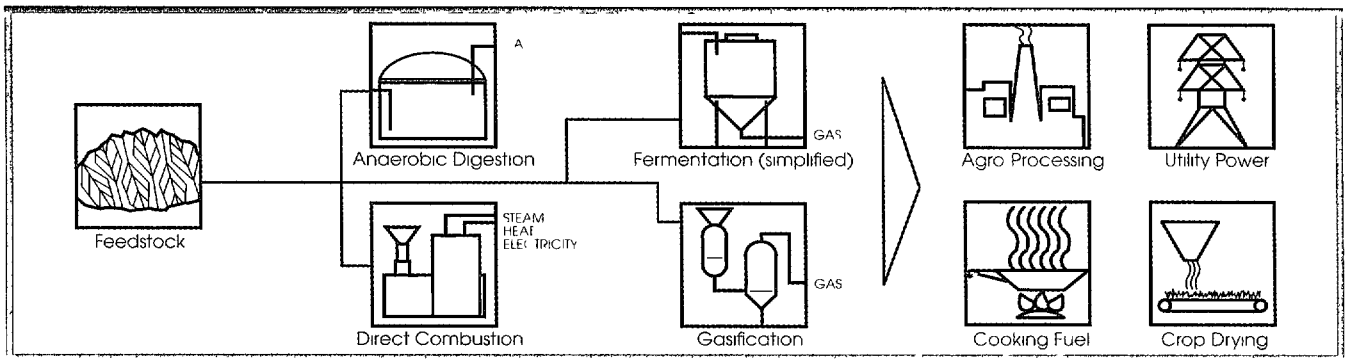
Biomass is a term that broadly encompasses plant matter and animal waste used for energy production Biomass may be used in a number of ways to produce energy, the most common being combustion, gasification, fermentation, and anaerobic digestion Biomass combustion is the direct burning of any plant matter The thermal output can produce direct heat for cooking or crop drying, forging kilns, heating water or raising steam in a boiler for electric power production or industrial processes High quality biomass combustion systems currently generate hot water steam and electricity for industries including forest products and food processing electric utilities and specialized markets such as rice and sugar mills

In gasification biomass products are heated in an oxygen starved environment and decompose without burning generating a volatile gas called producer gas This gas may be used in a furnace (direct heat gasification) or in an internal combustion engine Thousands of gasification systems have been installed at sites ranging from pulp and paper mills to large scale agricultural processing facilities

Biomass feedstocks can also be converted into valuable energy products through fermentation The starch feedstock is broken down into sugar with enzymes The sugar is then exposed to yeast or bacteria that converts it into ethanol and carbon dioxide A distillation process generally removes ethanol from the fermented liquid Ethanol is being used as a fuel for modified internal combustion engines, as an octane enhancer, and as a gasoline substitute

A fourth biomass energy conversion system is anaerobic digestion In this process, manure, agricultural residues, and/or specially grown crops are fed into a sealed container called an anaerobic digester or biogas plant, where they are broken down by special bacteria The gas produced is 50 to 60 percent methane The methane can be combusted to supply thermal capacity or to supply steam for a generator

Biomass Power



Photovoltaics

PV uses semiconductor solar cells to generate direct current (DC) from sunlight When combined with the appropriate balance of systems components, PV can be used to supply power for any electric application PV systems have no moving parts and thus require minimal maintenance, and the fuel source — sunlight — is free

PV power systems consist of the PV module, the supporting structure, and the balance of system components A PV module is a series of semiconductor solar cells that are connected together Depending on the application, a number of modules can be combined to form a PV array Through this grouping technique, PV systems can easily be tailored to meet the exact needs of an application

PV output is usually measured in peak Watts (Wp), which is the electrical output of the system at approximately noontime, or when the sun's intensity reaches its peak System outputs can range from a few peak Watts to a few hundred peak kilowatts (kWps) This rating is a function of both panel size and panel efficiency

Wind

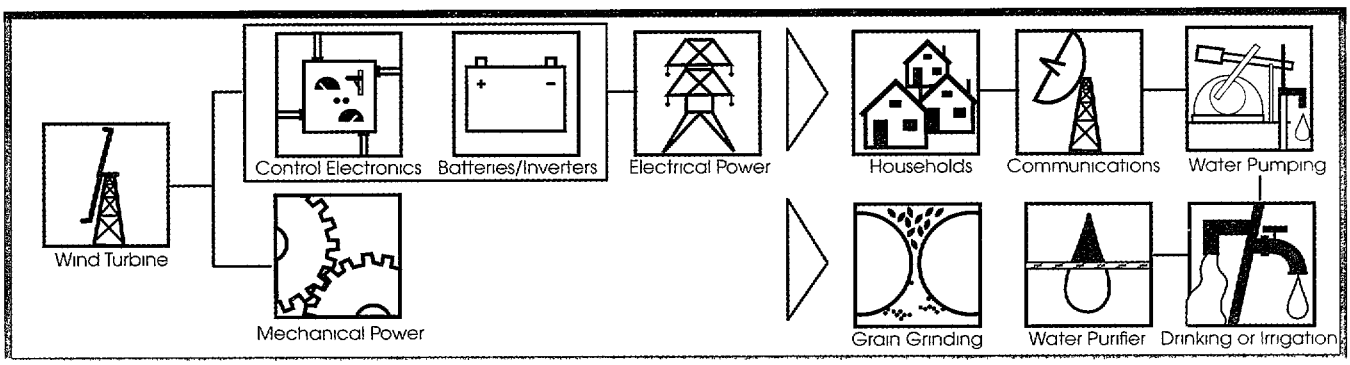
Wind turbines convert the energy in the wind to rotary motion, which in turn powers a generator to directly produce electricity or a drive shaft Small wind systems are available in sizes that produce a few hundred watts Larger sized turbines of up to approximately 1 megawatt can be either used as a stand alone system or combined with others to form a windfarm

While wind turbines need somewhat more maintenance than PV arrays (primarily due to moving parts) the majority of commercially available systems require minimum maintenance and the fuel source — wind — is free

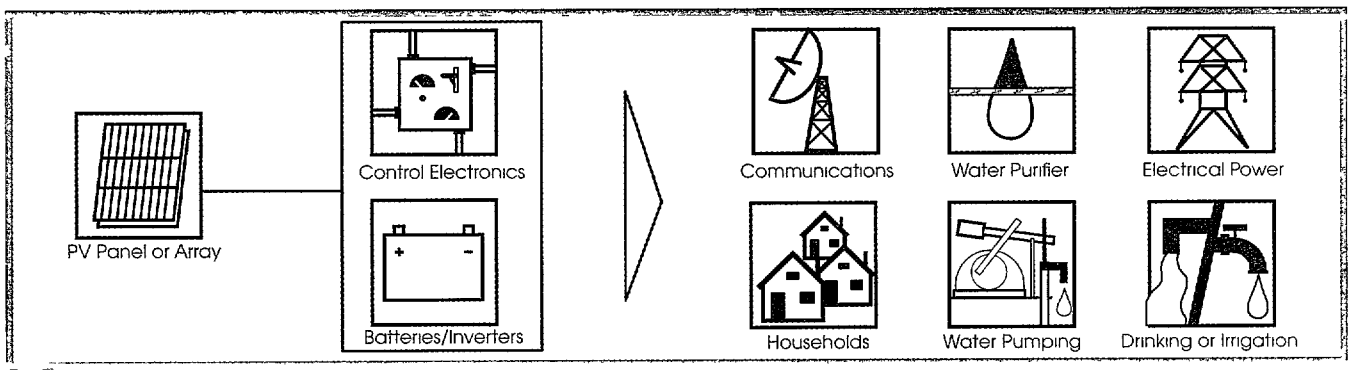
When wind turbine production is highly variable due to resource variance, wind turbines can be combined with a PV array or diesel generator to ensure energy production at times of low wind speed These combined systems are known as hybrid systems

Wind and PV systems are supplying power on hundreds of agricultural operations throughout the world

Wind



Photovoltaics



Balance of System Components

PV and wind systems provide intermittent, variable, DC current Therefore, for the majority of agricultural applications, PV and wind systems require balance of system components, such as batteries, inverters, and controllers

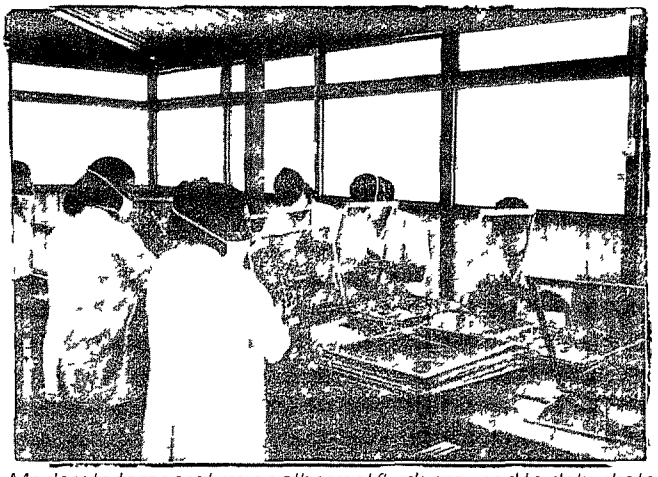
Batteries store energy in a chemical form for later use For remote power applications deep cycle batteries are generally recommended Shallow cycle batteries such as car batteries are generally not recommended because they can only be discharged to a 80 90 percent state of charge and only a handful of deeper discharges will often destroy them

Inverters convert DC to alternating current (AC) This capability is needed because PV panels and wind turbines produce DC power and most common electrical applications require AC power For off grid applications, the inverter must have stand alone capacity and high conversion efficiencies, especially at partial loads

Controllers act as the brains of a renewable energy system Controllers route the energy through the system components to the load The complexity of the controllers necessary for a renewable energy system depends on the size and complexity of the system and the preferences of the user

Small-Scale Geothermal

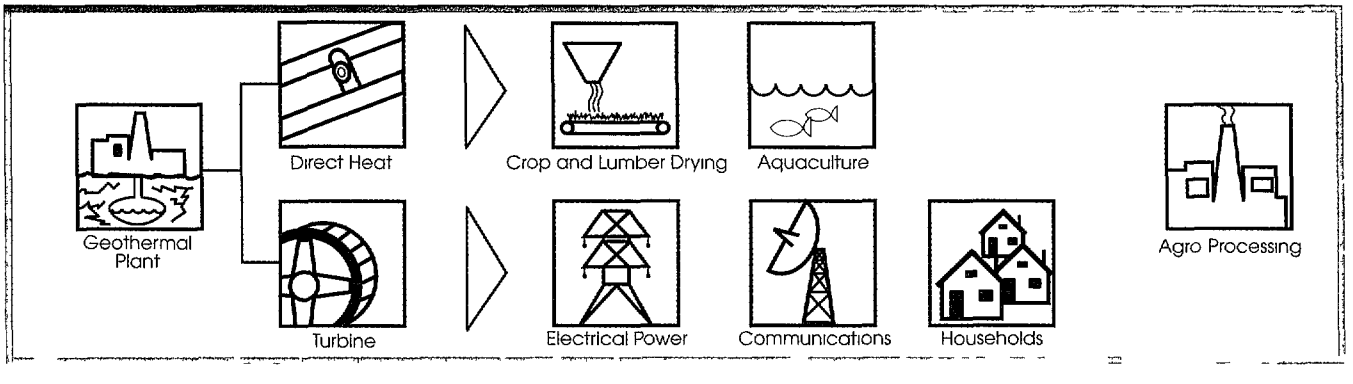
Small scale (under 15 MW) geothermal systems are classified according to their thermal and hydrological characteristics Numerous geological and physical factors — including the structural setting of the site, its predominant rock type, porosity and temperature distribution of the rock — combine to make each site and system unique The systems that are most attractive economically are those in which the above factors combine in a favorable way



Moderate temperature geothermal fluids are used to dehydrate tropical fruit in Guatemala

Geothermal resources can be used directly or indirectly by transforming thermal energy into electricity The higher the temperature of the heat bearing fluid, the wider the range of practical applications High temperature (above 100° C) geothermal fluids lend themselves to indirect applications, such as electricity generation and direct thermal applications, such as water distillation and industrial scale evaporation Low temperature (below 100° C) fluids lend themselves to direct thermal applications, such as heating greenhouses, drying food and lumber, raising fish, and providing water for cooking or bathing Geothermal resources are being used in a broad range of agricultural operations worldwide For example, in the photo above, women in a food processing facility in Guatemala rely on moderate temperature geothermal fluids to provide the thermal load necessary to dehydrate tropical fruit to produce snacks and ingredients for the making of bread, cereals, and other food products

Small-Scale Geothermal



Solar Thermal

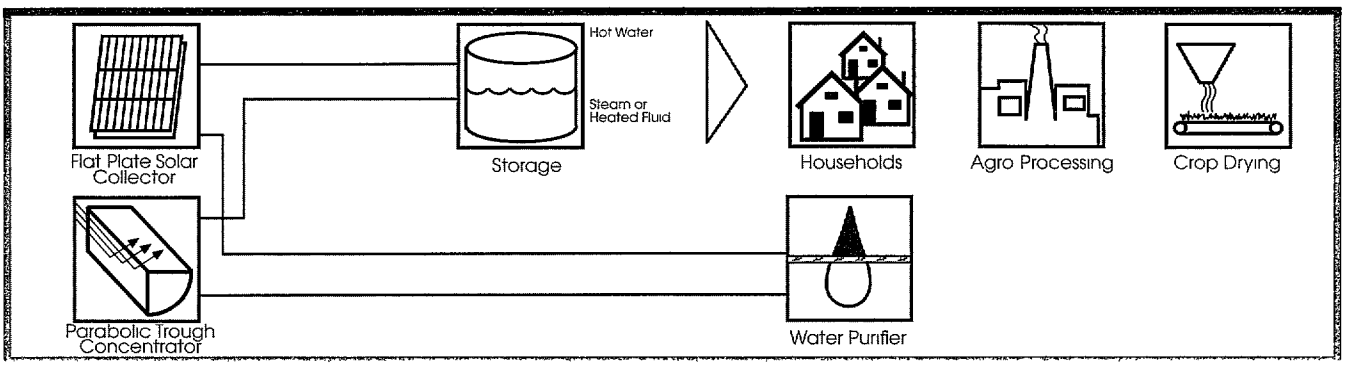
Solar thermal energy systems capture the sun's energy and convert it to heat There are two major types of solar thermal energy systems active and passive Active systems use a pump or blower to circulate water, air, or a heat exchanger fluid in a collector where it is heated by the sun's rays Active systems are broadly divided into flat plate systems, generally used for heating water or air, and concentrating systems, used for producing higher temperature fluids or steam The most common active system applications in agricultural enterprises are heating and purifying water, food processing, and crop drying The term "passive solar system" is commonly used to describe climate sensitive architectural designs, in which the building itself is used to buffer the interior from outside climatic swings

Micro- and Small-Scale Hydro

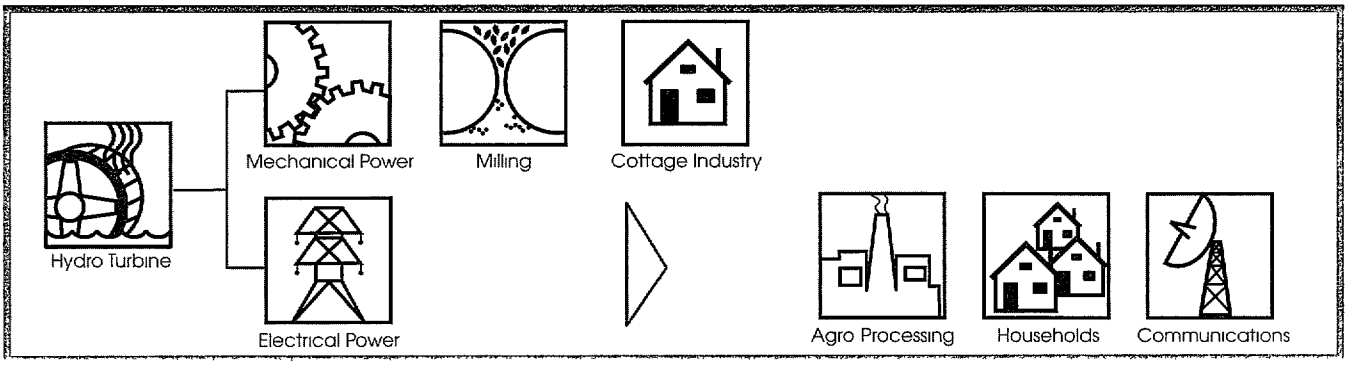
In a micro (under 50 kW) or small scale (between 50 kW and 15 MW) hydropower project, falling water is directed against a turbine, which is rotated by the force of the water The spinning turbine is either coupled directly to a load, such as grinding or milling, or connected to an electric generator set to supply electricity Hydro systems can provide continuous power as long as the water resource is sufficient In the past decade, increased attention has been given to micro and small scale hydroelectric plants that have minimal impact on the water resource eco system Micro and small scale hydro systems have no fuel costs, are nonpolluting, and typically — when developed and managed correctly — have little environmental impact Micro and small scale hydro systems are supplying power in a sustainable manner to agricultural enterprises throughout the world

Micro- and small-scale hydro systems have no fuel costs, are nonpolluting, and typically — when developed and managed correctly — have little environmental impact

Active Solar Thermal



Micro- and Small Scale Hydro



System Selection

The main considerations driving system selection are load, resource, quality of service, and cost

Load – System components must be sized so that a system can deliver the peak load PV components are most competitive at meeting small electric loads Wind, solar thermal, hydro, geothermal, and biomass systems become more competitive with somewhat larger electric and thermal loads Diurnal and seasonal load variations may also influence component selection

Resource – Obviously, the available resources greatly influence the configuration and costs of an energy system A good wind resource will favor the use of wind turbines, a good biomass resource will favor the use of a biomass system A central consideration is the variability of the resource both seasonally and daily Most locations experience seasonal variation in wind speeds, hydrology, and the biomass resource, but not in the geothermal resource These variations make it difficult to get consistent production from wind systems Biomass and hydro resources can often be cheaply stored for long periods of time to deliver a continuous source of electricity Solar systems have the issue of daily variation that must be dealt with

Quality of Service – All renewable energy systems require monitoring to ensure that a high quality of service is maintained Although the components of small scale PV, wind, geothermal, and hydro systems may be easy to maintain, the balance of system components require occasional supervision and maintenance Medium and large scale renewable energy generation units require daily supervision The absence of the necessity to constantly deliver fuel (except in the case of biomass based systems) is a major benefit that positively affects the quality of service in renewable energy systems

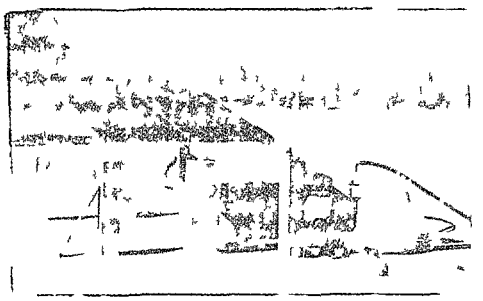
Cost – The installed cost of any renewable energy system depends on the hardware and software selected While these upfront capital costs are often higher than the initial costs of fossil fuel based systems, the savings in maintenance and fuel costs in the long term can result in substantial savings over the life of the system

A common error when evaluating energy systems is performing simple economic analysis based on the initial cost and short time periods Because the total cost of a project is the sum total of its initial and future costs, life cycle cost (LCC) analysis is more appropriate LCC analysis includes initial capital costs and all the future costs (equipment replacements operation and maintenance [O&M], and fuel) LCC is a useful tool that allows for a fair comparison of the economics of renewable energy and conventional technologies

The case studies on the following pages, developed by Sandia National Laboratories and Southwest Texas State University demonstrate two applications from the Mexico Renewable Energy Program where a renewable energy based system is the most cost competitive option on an LCC basis

Mexico Renewable Energy Program

The Mexico Renewable Energy Program is a joint initiative supported by USAID/Mexico, Government of Mexico, USAID s Office of Energy Environment and Technology and the U S Department of Energy s Sandia National Laboratories The program s goals are twofold increase the appropriate and sustainable use of renewable energy technologies in Mexico thereby expanding markets for both U S and Mexican industries and increase the use of renewable energy technologies as a mechanism for combating global climate change especially greenhouse gas emissions



One of the program's principal focus areas is agricultural development To date a number of PV and wind powered systems have been installed to power water pumping for livestock crop irrigation ranch communities and pasture irrigation as well as power electric fencing

The first stage of the program is a pilot phase designed to institutionalize renewable energy technologies in a number of productive use applications in rural areas More than 40 renewable energy companies from the United States and Mexico have already participated in the program More than 50 000 Mexicans have benefitted from the 200 renewable energy systems installed this year and the program team has identified a potential market in Mexico of more than US$1 billion for renewable energy technologies many of which are in agricultural applications

Case Study

Jeromin, Chihuahua, Mexico
Livestock Water Pumping

A good example of where a PV system is a more efficient choice than conventional technology is the Jeromin ranch site in central Chihuahua, Mexico The system owner previously operated a diesel generator to provide an average of 15,000 liters of water daily for his ranch The generator consumed 20 liters of fuel per day to pump the 15,000 liters An 848-Wp PV water pumping system was installed in March 1997 under the Mexico Renewable Energy Program The PV system is composed of 16 Solarex VRX 53 modules, Grundfos SP3A 10 pump, and SA-1500 controller

The results of the LCC analysis are provided in the figures Figure 1 shows the present value of all the future operational costs of each evaluated technology The initial capital costs in Figure 1 are twice the amount of the conventional technology, but in a 20-year period, the LCC for the conventional technology is four times the amount of the PV system The main factor causing this cost difference is the fuel consumption by the generator The fuel costs represent 78 percent of the total LCC for the conventional technology system Figure 2 shows that in spite of higher initial costs, after two years, the PV system actually represents a lower overall cost

LCC Assumptions
Jeromin Chihuahua Mexico

Economic Parameters	
Average discount rate	20%
Average inflation rate	13%
Average fuel escalation rate	13%
Real discount and fuel escalation rates	**7%**

	PV water pumping system (848 Wp)	Conventional system (15 kW generator & AC pump)
Initial capital cost	$10 491	$3 785
Replacements	Grundfos Pump – 20 years	AC Pump – 6 years Generator – 10 years
Operation and maintenance	1% initial capital cost	$200 year
O&M transportation	$72 – 12 visits	$312 – 52 visits
Fuel costs	None	7 980 liters/year $3 700/year

Figure 1

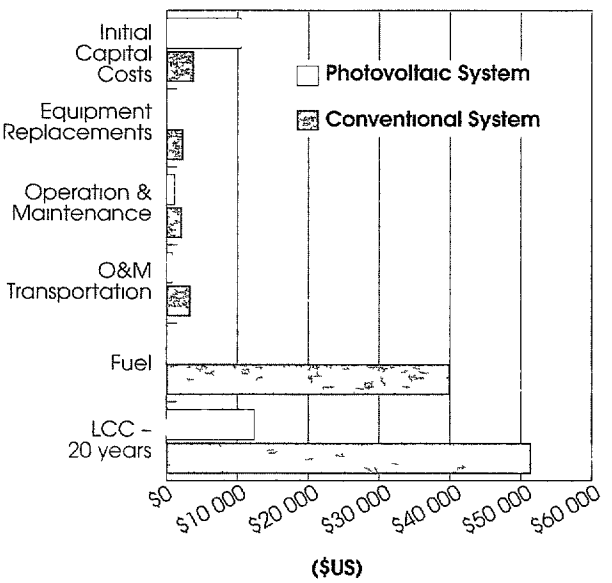
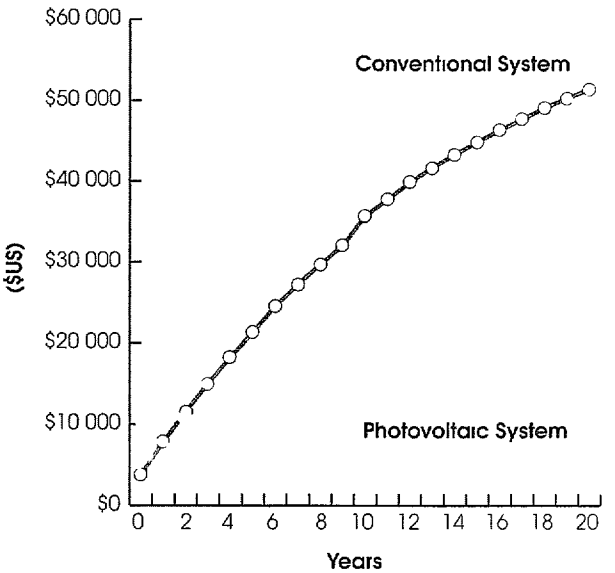


Figure 2



Case study provided courtesy of Sandia National Laboratories and Southwest Texas State University

Agua Blanca, Baja California Sur, Mexico
Livestock/Irrigation Pumping

Agua Blanca is a livestock/irrigation ranch with semi desert vegetation, located 120 kilometers north of La Paz, Mexico The ranch's operator has 1,001 hectares, with 25 hectares in buffalo grass As part of the Mexico Renewable Energy Program, an 800-Wp PV water pumping system was installed in March 1998 to replace an 8 Hp gasoline motor pump, which consumed an average of 2,000 liters of fuel per year The new PV water-pumping system is composed of 10 Kyocera KC 80 modules, Solarjack SCS 14 160 pump, and controller

The results of the LCC analysis are provided in the two figures Figure 3 shows the present value of all the future operational costs of each evaluated technology In this case, the initial costs are approximately twice the amount of the conventional technology, but in a period of 20 years the LCC for the PV water pumping system is lower The fuel costs represent 48 percent of the total LCC for the conventional technology system Figure 4 shows that in spite of higher initial solar energy capital costs, after six years, the PV system actually represents a lower overall cost to the operator

LCC Assumptions
Agua Blanca Baja California Sur Mexico

Economic Parameters	
Average discount rate	20%
Average inflation rate	13%
Average fuel escalation rate	13%
Real discount and fuel escalation rates	**7%**

	PV water pumping system (800 Wp)	Conventional system (6 0 kW gasoline motor pump)
Initial capital cost		
Initial system cost	$9 250	$2 018
Irrigation system	$1 325	$1 325
Water tank	$2 160	$2 160
Replacements	Solarjack pump 10 year	Gasoline motor pump 6 year
Operation and maintenance	1 initial capital cost	$200/year
O&M transportation	$72 - 12 visit	$312 52 visits
Fuel costs	None	2 078 liters/year $982/year

Figure 3

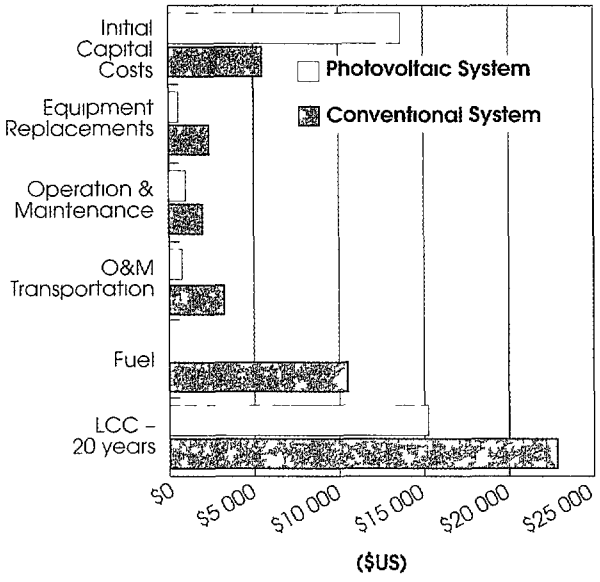
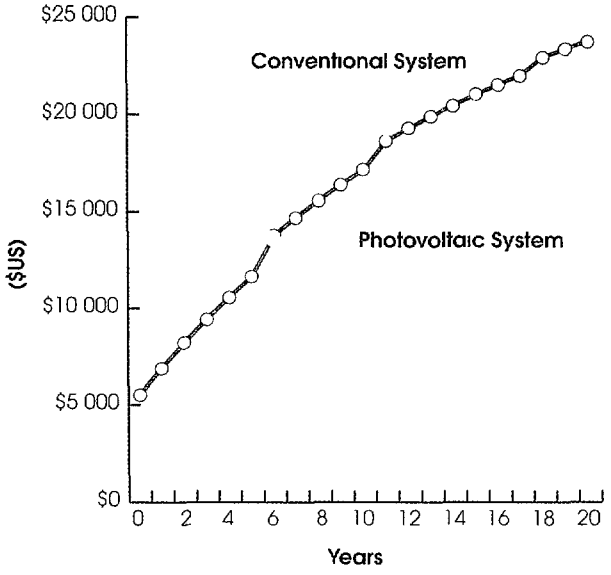


Figure 4



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